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Diffractive Dijet and W Production in CDF[1]

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Abstract. Results on diffractive dijet and W-boson production from CDF are reviewed and compared with predictions based on factorization of the diffractive structure function of the proton measured in deep inelastic scattering at HERA.

INTRODUCTION

In this paper, we summarize the published CDF results on diffractive dijet [1] and W-boson [2] production and compare them with predictions based on factorization of the diffractive structure function of the proton measured in $e^+p \to e^+ + [\gamma^* p \to Xp]$ deep inelastic scattering (DIS) at HERA [3,4]. Our comparison between CDF and HERA results has been reported in three previous papers [5–7], parts of which are reproduced here.

Hadronic diffraction is believed to be mediated by the exchange of the pomeron, which carries the quantum numbers of the vacuum. In the framework of QCD, pomeron exchange must involve the exchange of $q\bar{q}$ and/or gg pairs in a color-singlet state. However, the question arises whether the pomeron, although virtual, has a *unique* partonic structure, as do real hadrons. Such a structure, if it exists, could be probed in hard diffractive processes. Figure 1 shows (a) a schematic diagram and (b) the event topology for diffractive production. Since there is no color exchanged between the colorless pomeron and the parent nucleon, a rapidity gap (region devoid of particles) emerges as a characteristic signature of pomeron exchange. Such gaps can be used to tag diffractive production. Another way of tagging diffraction is provided by the recoil $\bar{p}$ or p. The CDF Collaboration has obtained results for hard diffraction in $\bar{p}p$ collisions at $\sqrt{s} = 1800$ GeV using both tagging techniques. The results we report here are were obtained using the rapidity gap method.

At HERA, where ~ 28 GeV electrons are brought into collision with ~ 800 GeV protons ($\sqrt{s} \approx 300$ GeV), diffraction has been studied both in photoproduction and in high Q^2 DIS. The H1 and ZEUS Collaborations have measured the diffractive structure function of the proton and its internal factorization

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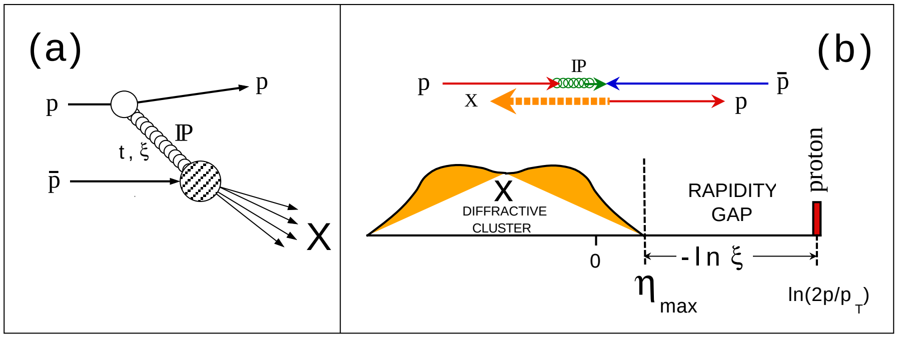

FIGURE 1. (a) Schematic diagram and (b) event topology for $p\bar{p}$ diffraction dissociation.

properties. Figure 2 shows the kinematics of a DIS diffractive collision.

In analogy with the $F_2(Q^2, x)$ structure function, the 4-variable diffractive

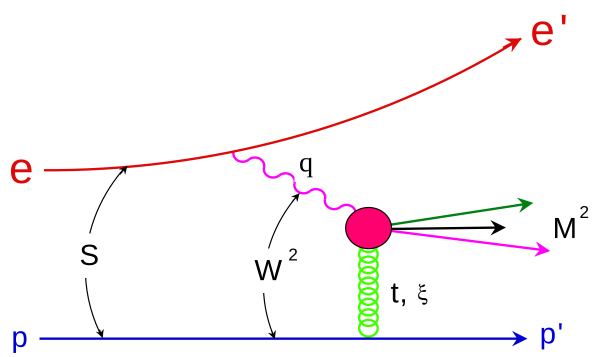

FIGURE 2. Schematic diagram of a diffractive DIS collision involving a virtual photon, emitted by an electron, and a virtual pomeron, emitted by a proton.

structure function of the proton, $F_2^{D(4)}(Q^2, x, \xi, t)$, is defined through the cross section equation

$$\frac{d^4\sigma}{dQ^2\,dx\,d\xi\,dt} = \frac{4\pi\alpha^2}{x\,Q^4} \cdot f(y) \cdot F_2^{D(4)}(Q^2, x, \xi, t) \tag{1}$$

where x and y are the Bjorken DIS variables, $f(y) \equiv 2 - 2y + y^2/[2(1+R)]$, and ξ is the fraction of the proton's momentum taken by the pomeron. The t-integrated diffractive structure function, $F_2^{D(3)}$, was determined from the data by assuming $R = 0$ in $f(y)$. The reported measured values for $F_2^{D(3)}$ correspond to cross sections given by

$$\frac{d^3\sigma}{dQ^2\,d\beta\,d\xi} \stackrel{|t|<1}{\equiv} \frac{4\pi\alpha^2}{\beta Q^4} \cdot f(y) \cdot F_2^{D(3)}(Q^2, \beta, \xi) \tag{2}$$

where $\beta \equiv x/\xi$ represents the fraction of the momentum of the pomeron carried by the interacting quark. Below we will use the measured $F_2^{D(3)}$ structure function to predict the rate for diffractive W production at the Tevatron and compare the prediction with the value measured by CDF.

THE CDF DETECTOR

The components of the CDF detector relevant to studies of diffractive dijet and W-boson production using rapidity gaps are [8] the Beam-Beam Counters (BBC), the Central Tracking Chamber (CTC), and the calorimeters. The BBC consist of a square array of 16 scintillation counters placed at $\pm z$ position of 6 m from the center of the detector. The calorimeters have a tower geometry with segmentation of 0.1 units in η and 15° (5° for $|\eta| > 1.1$) in ϕ. The η-coverage is:

BBC	$3.2 < \|\eta\| < 5.9$
CTC	$\|\eta\| < 1.8$
CAL: central	$\|\eta\| < 1.1$
CAL: plug	$1.1 < \|\eta\| < 2.4$
CAL: forward	$2.2 < \|\eta\| < 4.2$

A "particle" is defined as a hit in a BBC, a track with $P_T > 300$ MeV in the CTC, or a calorimeter tower with measured $E_T > 200$ MeV (corrected $E_T >\sim 300$ MeV), except for the region $2.4 < |\eta| < 4.2$ for which the requirement is a tower *energy* of $E > 1.5$ GeV.

DIFFRACTIVE DIJET PRODUCTION

CDF searched for diffractive dijet production in a sample of 30352 dijet events with a single-vertex (to exclude events due to multiple interactions), in which the two leading jets have $E_T > 20$ GeV and are both at $\eta < 1.8$ or $\eta > 1.8$. No requirement was imposed on the presence or kinematics of extra jets in an event. Figure 3 shows the correlation of the BBC and forward ($|\eta| > 2.4$) calorimeter tower multiplicities in the η-region opposite the dijet system. The excess in the 0-0 bin is attributed to diffractive production. After subtracting the non-diffractive background and correcting for the single-vertex selection cut, for detector live-time acceptance and for the rapidity gap acceptance (0.70 ± 0.03), calculated using the POMPYT Monte Carlo program [1] with pomeron $\xi < 0.1$, the "Gap-Jet-Jet" fraction (ratio of diffractive to non-diffractive dijet events) was found to be

$$R_{GJJ} = [0.75 \pm 0.05(stat) \pm 0.09(syst)]\% = (0.75 \pm 0.10)\%$$
$$(E_T^{jet} > 20 \text{ GeV},\ |\eta|^{jet} > 1.8,\ \eta_1\eta_2 > 0,\ \xi < 0.1)$$

Figure 4 shows pomeron-ξ distributions of dijet events generated by a POMPYT Monte Carlo simulation for $\xi < 0.1$ and a hard gluon pomeron structure. The jets were required to have $E_T^{jet} > 20$ GeV and be in the region $1.8 < |\eta| < 3.5$ with $\eta_1 \cdot \eta_2 > 0$.

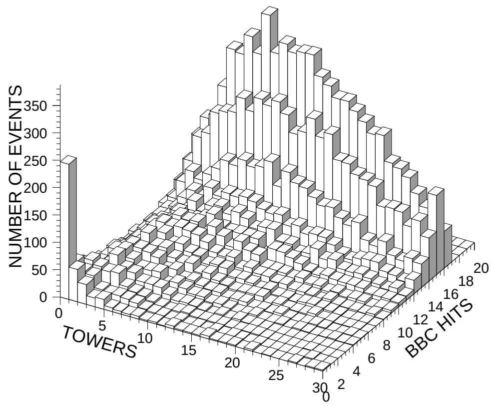

FIGURE 3. Tower versus BBC multiplicity for dijet events with both jets at $\eta > 1.8$ or $\eta < 1.8$.

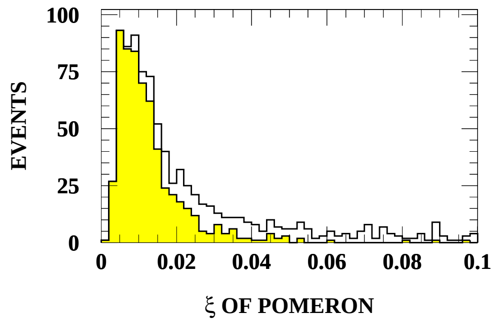

FIGURE 4. Monte Carlo pomeron ξ distributions for diffractive dijet events with jet $E_T > 20$ GeV and $1.8 < |\eta| < 3.5$ generated by POMPYT using a hard-gluon pomeron structure. The shaded area represents the subset of Monte Carlo events with zero BBC and forward calorimeter multiplicities, corresponding to the data in the (0,0) bin of Fig. 3

DIFFRACTIVE W PRODUCTION

CDF made the first observation [2] of diffractive Ws and measured the W production rate using a sample of 8246 events with an isolated central e^+ or e^- ($|\eta| < 1.1$) of $E_T > 20$ GeV and missing transverse energy $\not\!\!E_T > 20$ GeV. In searching for diffractive events, CDF studied the correlations of the BBC multiplicity, N_{BBC}, with the sign of the electron-η, η_e, or the sign of its charge, C_e. In a diffractive $W^\pm \to e^\pm\nu$ event produced in a $\bar{p}$ collision with a pomeron emitted by the proton, a rapidity gap is expected at positive η (p-direction), while the lepton is boosted towards negative η (angle-gap correlation). Also, since the pomeron is quark-flavor symmetric, and since, from energy considerations, mainly valence quarks from the $\bar{p}$ participate in producing the W, approximately twice as many electrons as positrons are expected (charge-gap correlation).

Figure 5 shows the BBC versus tower multiplicity for two event samples characterized by the correlation between the pseudorapidity of the BBC whose multiplicity is plotted, η_{BBC}, and the η_e or C_e, as follows: (a) *doubly-correlated* events, for which $\eta_e \cdot C_e > 0$ and $\eta_e \cdot \eta_{BBC} < 0$, and (b) *doubly-anticorrelated* events, for which $\eta_e \cdot C_e > 0$ and $\eta_e \cdot \eta_{BBC} > 0$. Monte Carlo simulations show that diffractive W events are expected to have low BBC or tower multiplicities (in the range 0-3), and that there should be $\sim$ 4 times as many doubly-correlated than doubly-anticorrelated events. This diffractive signature is satisfied by the small number of events at low multiplicities in Fig. 5.

The probability that the observed excess is caused by fluctuations in the non-diffractive background was estimated to be 1.1×10^{-4}.

Figure 6 shows pomeron-ξ distributions of W events generated by POMPYT. Correcting for acceptance, the ratio of diffractive to non-diffractive W production is:

$$R_W = [1.15 \pm 0.51(stat) \pm 0.20(syst)]\% \ \ (\xi < 0.1)$$

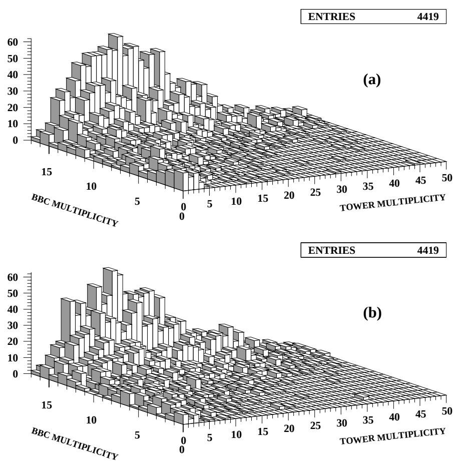

FIGURE 5. Tower versus BBC multiplicity for W events:
(a) (angle$\otimes$charge)-correlated;
(b) (angle$\otimes$charge)-anticorrelated.

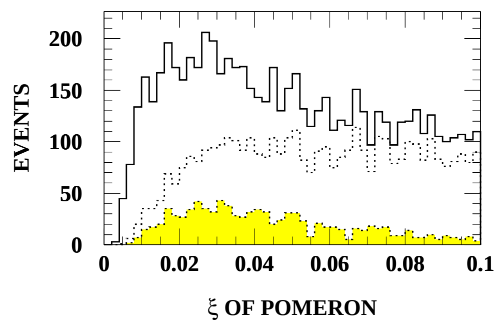

FIGURE 6. Monte Carlo pomeron ξ distributions for diffractive W events generated by POMPYT using a hard-quark pomeron structure: *(solid line)* all events; *(dotted line)* events with a central electron; *(shaded area)* events with a central electron and 0, 1 or 2 hits in the (angle$\oplus$charge)-correlated BBC (corresponding to the signal).

THE GLUON FRACTION OF THE POMERON

By combining the diffractive W and dijet results, CDF extracted the gluon fraction of the pomeron, f_g. Assuming the standard pomeron flux, the measured W and dijet fractions trace curves in the plane of D versus f_g, where D is the total momentum fraction carried by the quarks and gluons in the pomeron. Figure 7 shows the $\pm 1\sigma$ curves corresponding to the results. From the diamond-shaped overlap of the W and dijet curves, CDF obtained $f_g = 0.7 \pm 0.2$. This result, which is independent of the pomeron flux normalization, agrees with the result obtained by ZEUS [3] from DIS and dijet photoproduction (dashed-dotted line in Fig. 7). For the D-fraction, CDF obtained the value $D = 0.18 \pm 0.04$. In the next section we will show that the decrease of the D-fraction from HERA to the Tevatron can be accounted for by the pomeron flux renormalization factor [9]. The dashed lines are the $\pm 1\sigma$ curves of the UA8 diffractive dijet results [10]. To compare UA8 with CDF, the UA8 fractions must first be multiplied by the ratio of the renormalization factors at the two energies, which is [9] $D_{CDF}/D_{UA8} \approx 0.7$. Within the errors, the results of the two experiments are in good agreement.

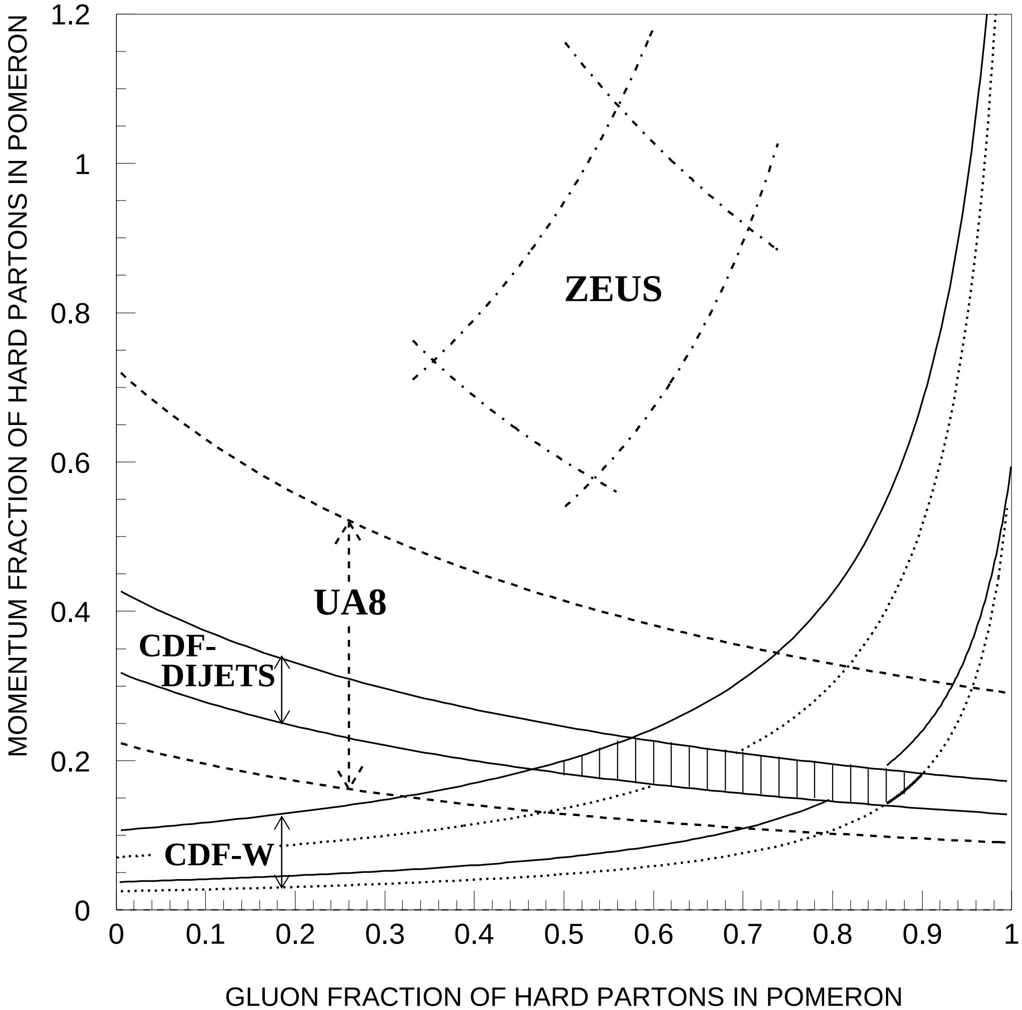

FIGURE 7. Momentum fraction versus gluon fraction of hard partons in the pomeron evaluated by comparing measured diffractive rates with Monte Carlo predictions based on the *standard* pomeron flux and assuming that only hard pomeron partons participate in the diffractive processes considered. Results are shown for ZEUS (dashed-dotted), UA8 (dashed) and the CDF-dijet and CDF-W measurements. The CDF W result is shown for two (dotted) or three (solid) light quark flavors in the pomeron . From the shaded diamond-shaped region of overlap of the CDF W and dijet production bands a gluon fraction of $f_g = 0.7 \pm 0.2$ and a momentum sum rule discrepancy factor of $D = 0.18 \pm 0.04$ were extracted [1]. The latter can be considered to be a discrepancy in the pomeron flux, if the momentum sum rule for the pomeron is assumed. The measured value of the pomeron flux discrepancy is in general agreement with the renormalized flux prediction [9].

FROM HERA TO THE TEVATRON

The diffractive structure function $F_2^{D(3)}$ measured in DIS at HERA (Eq. 2) can be used directly to calculate the rate of diffractive W-boson production in $p\bar{p}$ collisions at $\sqrt{s} = 1800$ GeV. Such a calculation yields [5] $R_W = 6.7\%$ for the ratio of diffractive to non-diffractive W production (a similar result has been obtained [12] by L. Alvero, J. Collins, J. Terron and J. Whitmore). The measured value [2] $R_W = (1.15 \pm 0.55)\%$ is smaller than the predicted 6.7% by a factor of 0.17 ± 0.08. The deviation of this factor from unity represents a *breakdown of factorization.*

Assuming that the rapidity gap probability (ξ-distribution) in $F_2^{D(3)}$ (Eq. 2) scales to the total gap probability (integrated over all available phase space), it has been shown [5] that the ratio of the scaling factors from HERA to the Tevatron is 0.19. This ratio agrees with the discrepancy factor of 0.17 ± 0.08 between the measured R_W and the standard factorization prediction, as well as (or equivalently) with the momentum sum rule discrepancy $D = 0.18 \pm 0.04$ obtained from the comparison of the diffractive W and dijet rates. Thus, the diffractive structure function with a *scaled* gap probability provides a "transatlantic diffractive bridge" connecting HERA with the Tevatron!

The scaling of the gap probability in the diffractive structure function is equivalent to the pomeron flux renormalization scheme proposed to unitarize the soft diffraction triple-pomeron amplitude [9]. Thus, the breakdown of factorization in hard diffraction is traced back to the breakdown observed in soft diffraction [5–7,9,13].

In both cases, soft and hard, factorization breaks down to preserve unitarity. The interesting fact is that the breakdown occurs in a way that respects a scaling law, namely the scaling of the (ξ, t)-differential gap probability to the total gap probability, integrated over all available (ξ, t)-space for any given process [7].

CONCLUSION

Experiments at HERA and at $p\bar{p}$ Colliders show that the pomeron has a hard partonic structure, which consists of $\sim 70\%$ gluons and $\sim 30\%$ quarks. Predictions using the diffractive structure function of the proton measured in DIS at HERA are larger than the W and dijet rates measured at the Tevatron by a factor of ~ 6. This breakdown of factorization can be accommodated by scaling the rapidity gap probability distribution, which appears in the diffractive structure function as a ξ-dependent factor multiplying a function of Q^2 and β, to the total gap probability. The scaling of the gap probability is equivalent to the pomeron flux renormalization hypothesis introduced [9] to account for the s-dependence of the soft $p\bar{p}$ single diffraction dissociation cross section.

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